WEAR PROPERTY OF METAL MATRIX COMPOSITE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical & Materials Engineering

By

AVINASH KUMAR (107MM034)

SATYAJEET SINGH (107MM037)

Department of Metallurgical & Materials Engineering

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Under the Guidance of **Prof. A. BASU**

Department of Metallurgical & Materials Engineering

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, "**WEAR PROPERTY OF METAL MATRIX COMPOSITE** " submitted by **Avinash Kumar (107MM034)** and **Satyajeet Singh (107MM037)**, in partial fulfillments for the requirements for the award of **Bachelor of Technology Degree** in **Metallurgical and Materials Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Prof. A. Basu

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ACKNOWLEDGEMENT

We wish to express our deep sense of gratitude to **Prof. A. Basu**, our guide, for his consistent encouragement, guidance and support to carry out and complete this project, and for giving us an opportunity to work on this project.

We are sincerely grateful to **Prof. B. B. Verma**, Head of the Department of Metallurgical and Materials Engineering, NIT-Rourkela, for providing all the necessary facilities in the department.

We would be highly obliged to extend our thanks to **Mr. Uday Kumar Sahu** and **Mr. Rajesh Patnaik**, and **Mr. Hembram** for their immense support and help rendered while carrying out our experiments, without which the completion of this project would have been at stake.

We would also like to thank all the staff members of MME Dept., NITR and everyone who in some way or the other has provided us valuable guidance, suggestion and help for this project.

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ABSTRACT

The purpose of this paper was to study the wear property of Cu-SiC composite manufactured by powder metallurgy route with varying compositions and sintering temperatures. 12 different samples (SiC compositions 0, 5, 10 and 15 Vol.%) of the composite were made by mixing, cold pressing and sintering at three different temperatures (700, 775 and 850 ^{o}C). The change in densities and hardness values were noted and studied. Then XRD and SEM analysis of the samples were done to study the phases present and their distributions along with idea of composition. Hardness and wear studies were carried out to judge the surface mechanical properties of the composites prepared. Wear mechanism was also studied using the scanning electron microscope.

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LIST OF FIGURES

1. INTRODUCTION

Copper is considered to be one of the vital elements in today's world due to its wide range of applications in various fields. It is mainly used in transmission wires, cables, generators, transportation vehicles, musical instruments, construction of buildings, roofs, etc. Such wide range of uses is possible due to the excellent properties of copper.

Important Properties of Copper [1]:-

- Excellent electrical and thermal conductivity.
- Resistance to corrosion.
- Ductile and easily joinable.
- Non-magnetic and easily alloyable.
- Anti-Bacterial and recyclable.

General and Atomic Properties [2]:-

- Atomic Number : 29
- Atomic Weight : 63.546
- Melting Point : 1356 K
- Boiling Point : 2868 K
- Density (at 293K): 8940 kg per cubic metre.
- Crystal Structure : Face centered cubic.

The major drawback associated with copper is its relatively low strength. To improve its strength related properties it is often alloyed or reinforced with suitable material to form a composite. Generally reinforcing with SiC particles imparts high strength to the copper matrix and also improves its wear properties to a large extent. We know that pure copper is an excellent conductor of electricity. Generally increasing the strength of copper by forming an alloy or a composite can reduce its electrical conductivity. So, there has to be a compromise between increasing the strength of pure copper and reducing its electrical conductivity, otherwise we can loose a chunk of the applications of pure copper. It has been observed that [3] the strength and ductility of the copper alloys increase as we reduce the temperature. The different compounds of copper found in nature also don't have great strength either. Therefore to make copper suitable

for structural applications, suitable copper alloys like bronze or composites with copper as matrix and reinforcements such as SiC particles are being manufactured. Recently the use of copper composites has significantly increased due to the ongoing resarch work in this field and this has led to the continuous improvement in properties of copper.

SiC is a compound of silicon and carbon known as carborundum. The three major polytypes of SiC are 3C-SiC(β), 4H-SiC and 6H-SiC(α). All the three polytypes of SiC are generally very hard, inert and have good thermal conductivity [4]. Silicon Carbide is treated as a semiconductor i.e. its conductivity is not as high as a good conductor and not as low as an insulator. Silicon carbide as such, because of its high hardness, has got a number of applications such as in cutting tools, jewellery, automobile parts, electronic circuits, structural materials, nuclear fuel particles, etc. SiC can be used as reinforcement in the form of particulates, whiskers or fibers to improve the properties of the composite. When embedded in metal matrix composites SiC certainly improves the overall strength of the composite along with corrosion and wear resistance.

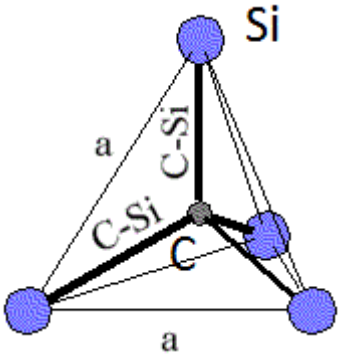


Figure 1: Tetragonal bonding between C & Si [4]

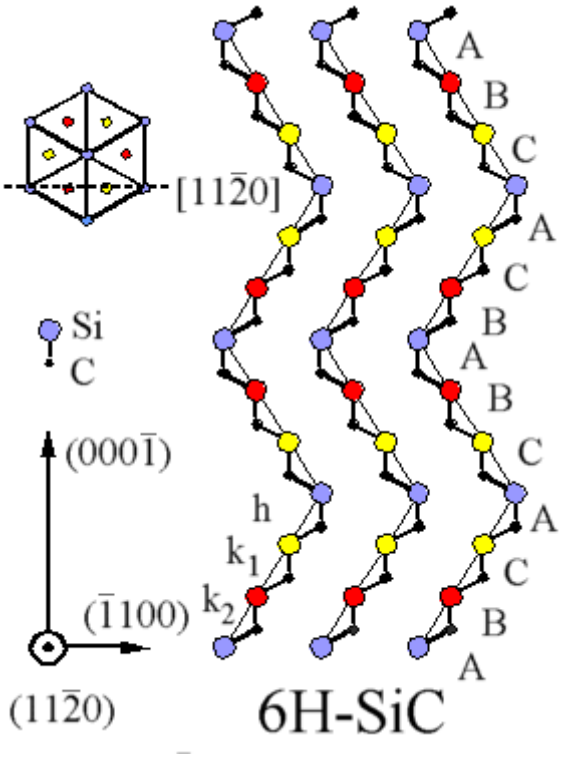


Figure 2: [11$\bar{2}$0] plane in 6H-SiC [4]

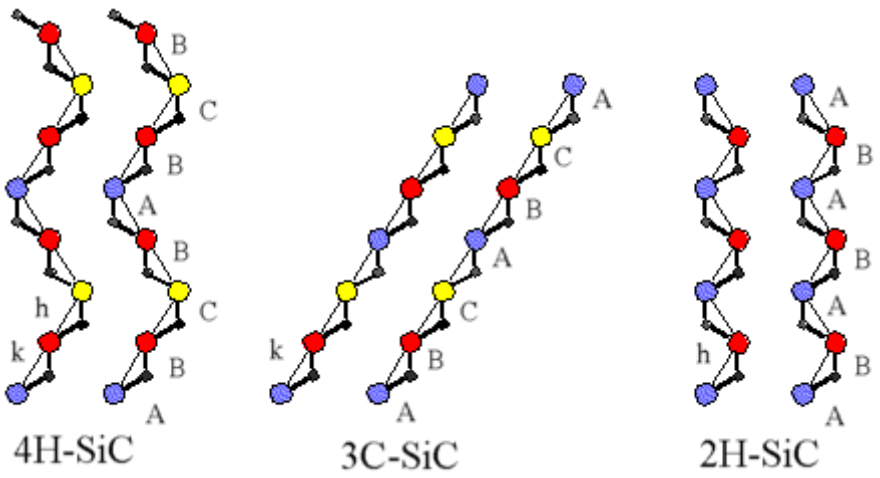


Figure 3: [11 $\bar{2}$ 0] planes in 4H-SiC, 3H-SiC and 2H-SiC [4]

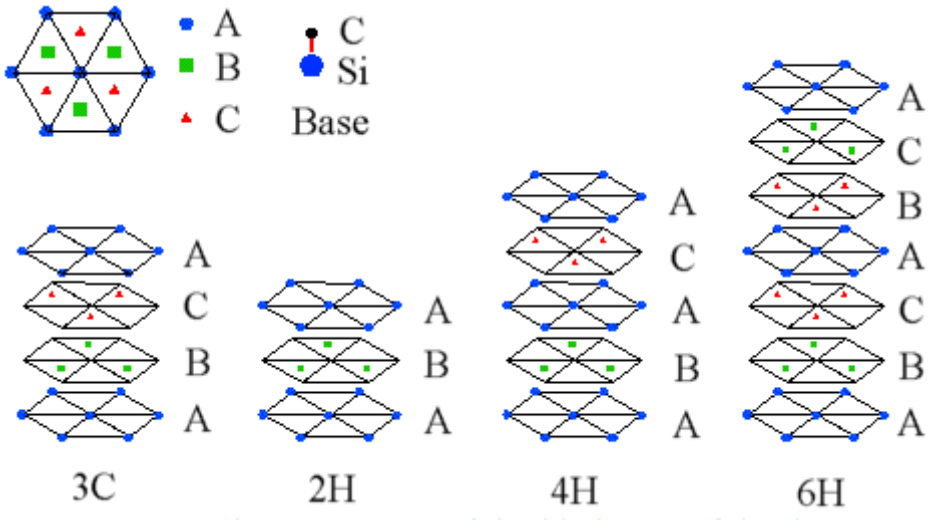


Figure 4: Stacking sequence in the polytypes of SiC [4]

2. LITERATURE SURVEY

2.1 COMPOSITE

Composites are usually man-made materials but can also be sometimes natural such as wood [5]. They are mostly formed by the combination of two different materials separated by a distinct interface. The properties of a composite as a whole are enhanced as compared to the properties of its components. The two phases that make up a composite are known as reinforcing phase and matrix phase. The reinforcing phase is embedded in the matrix phase and mainly provides strength to the matrix. The reinforcing phases usually found in composites are particles, fibers or sheets and the matrix materials can be of the form of polymers, ceramics or metals.

2.2 WHY TO USE COMPOSITE ?

The most important advantage associated with composites is their high strength [6] and stiffness along with low weight. This high strength to weight ratio enables the greater usage of composites in space applications where being light and strong is given prime importance. Also, in composites the fibers present share the load applied and prevents the rapid propagation of cracks as in metals. Another advantage of composites is the flexibility associated with their designing method. It is because they can be moulded to form various shapes be it easy or complex. Composites with proper composition and manufacturing can withstand corrosive and high temperature environments. With all these advantages it is obvious to think why the composites have not replaced the metals. One major drawback linked with the composites is its high cost which is often due to the use of expensive raw materials and not due to the manufacturing processes.

2.3 CLASSIFICATION OF COMPOSITES

On the basis of the reinforcing phase and matrix phase the composites can be classified into the following:

2.3.1 ON THE BASIS OF REINFORCEMENT

2.3.1.1 PARTICLE REINFORCED COMPOSITE

Particle reinforced composites are again divided into large particle composites and dispersion strengthened composites [7]. In large particle composites the size of particles is larger than that of dispersion strengthened composites. If the bonding is good then the matrix movement can be restrained. Concrete and Reinforced Concrete are examples of large particle composites. In dispersion strengthened the particle size varies from 10-100 nm. The small particles are dispersed throughout the matrix and prevent plastic deformation by blocking the motion of dislocations. Sintered Aluminium Powder (SAP) is an example of dispersion strengthened composite.

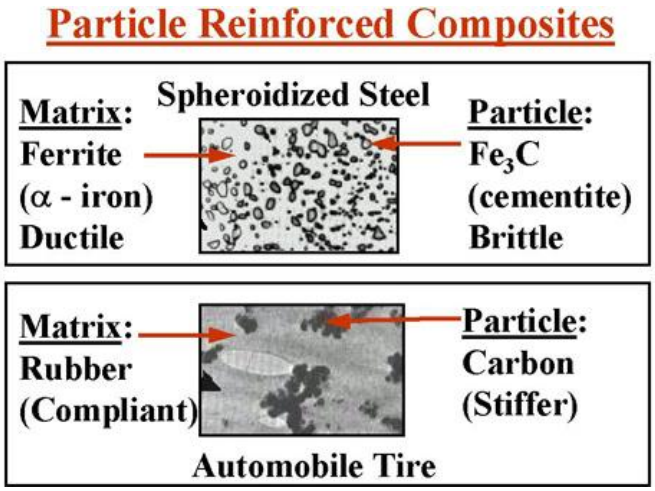


Figure 5: Particle Reinforced Composites

2.3.1.2 FIBER REINFORCED COMPOSITE

Fibers are responsible for high strength and stiffness ratio to weight of the composite [8]. This class can be further subdivided into continuous and discontinuous fibers. Continuous fibers are those which have lengths normally greater than 15 times the critical length ($l > 15\ l_c$) and discontinuous fibers have lengths shorter than this. The discontinuous fibers can be aligned or randomly oriented. It is obvious that for better strength of the composite and better load transfer the fibers should be continuous. Examples of some fibers are carbon fibers, boron fibers, E-glass fibers, SiC fibers, etc.

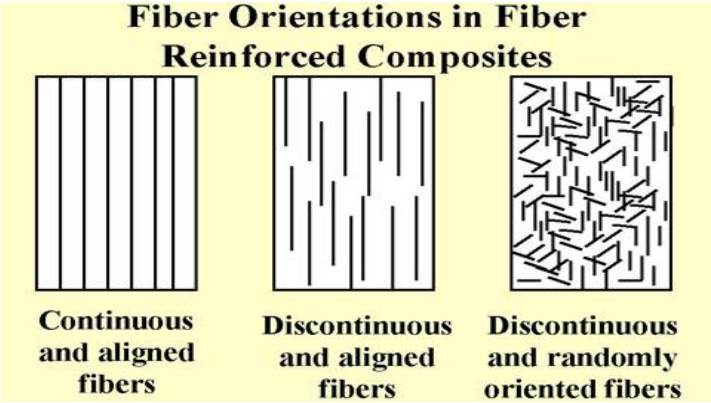


Figure 6: Fiber Reinforced Compoites

2.3.1.3 STRUCTURAL COMPOSITE

The most commonly used structural composites are laminar composites and sandwich panels [8]. Laminar composites are made up of sheets or panels which are two-dimensional and the layers are arranged such that in each successive layer the orientation of the direction of high strength changes. As a result, high strength can be found in various directions in the 2-D plane. In a sandwich panel, a thicker core separates two thin sheets. The sheets or faces are bonded adhesively to the core. The core is generally light in weight and provides support to the outer faces. It should be able to prevent buckling of the sandwich panel. The sheets present in outward direction should be made from a strong and stiff material like steel, titanium, Al alloys, etc to sustain various stresses due to loading.

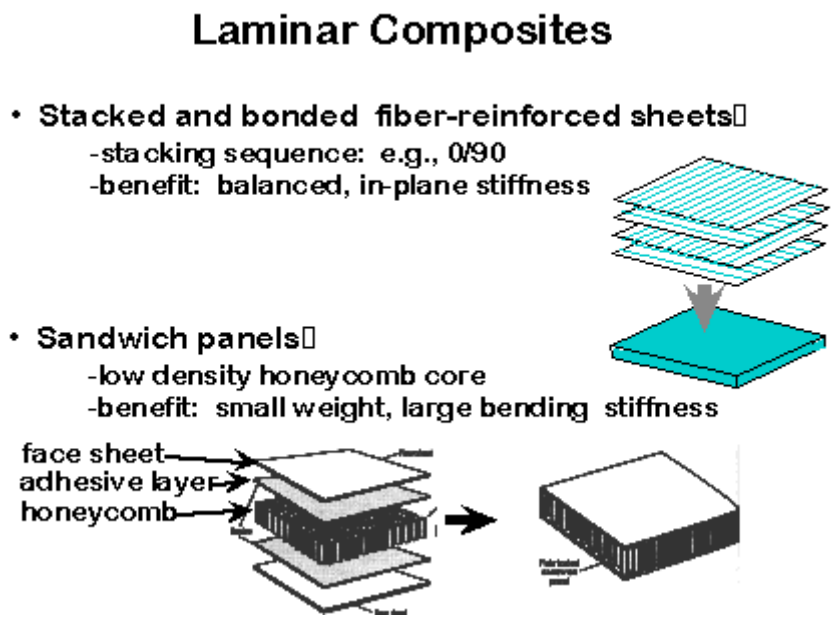


Figure 7: Laminar Composites and Sandwich Panels

2.3.2 ON THE BASIS OF MATRIX

2.3.2.1 POLYMER MATRIX COMPOSITE

They contain polymer as the matrix phase and fibers such as E-glass, carbon or aramid as the reinforcing phase [8]. The different varieties of Polymer-Matrix Composites (PMC) which are mostly used are Glass Fiber-Reinforced Polymer (GFRP) composites, Carbon Fiber-Reinforced Polymer (CFRP) composites and Aramid Fiber-Reinforced Polymer Composites. The most commonly used polymers as matrix are vinyl esters and polyesters. PMCs are widely used based on their properties and ease of fabrication.

2.3.2.2 CERAMIC MATRIX COMPOSITE

This class of composites contains ceramic materials as matrix phase. CMCs are developed primarily to improve the fracture toughness of ceramic materials [8]. This makes the CMCs to be used in extreme environments of high temperature and stress state. The dispersed phase plays a major role in preventing the propagation of cracks. This dispersed phase can be fibers, particles or whiskers. Various mechanisms like transformation toughening crack bridging, crack deflection, etc help in hindering the growth of a crack.

2.3.2.3 METAL MATRIX COMPOSITE

The matrix phase for a MMC is a metal often which is ductile. MMCs are manufactured with aims to have high strength to weight ratio, high resistance to abrasion and corrosion, resistance to creep, good dimensional stability, and high temperature operability [8]. The main advantages that MMCs possess over CMCs are the usability at high temperatures, and resistance to corrosion by organic fluids. MMCs are used in industries like automobile and aerospace. Mainly Aluminium and Copper are used as the metal matrix. Composite degradation may be a problem while using MMC at elevated temperatures. To avoid that the reinforcement is given a protective surface coating or the composition of the matrix alloy is modified.

2.3.2.4 HYBRID COMPOSITE

In a hybrid composite usually there are two or more fibers which are different from one another in a single matrix phase [8]. The most commonly used hybrid composite is the one which contains polymeric resin as the matrix and both glass and carbon fibers as reinforcing phase. We get anisotropic properties in most of the hybrid composites. The overall properties of a hybrid composite are better than the composites having only one fiber as reinforcing phase.

2.4 METAL MATRIX COMPOSITE AND ITS SYNTHESIS

It is obvious now that metal matrix composites contain a metal or an alloy as the matrix phase. There are several MMCs that we come across more often such as Al-SiC or Cu-SiC composites. Mostly the reinforcement phases incorporated are fibers, particulates or whiskers.

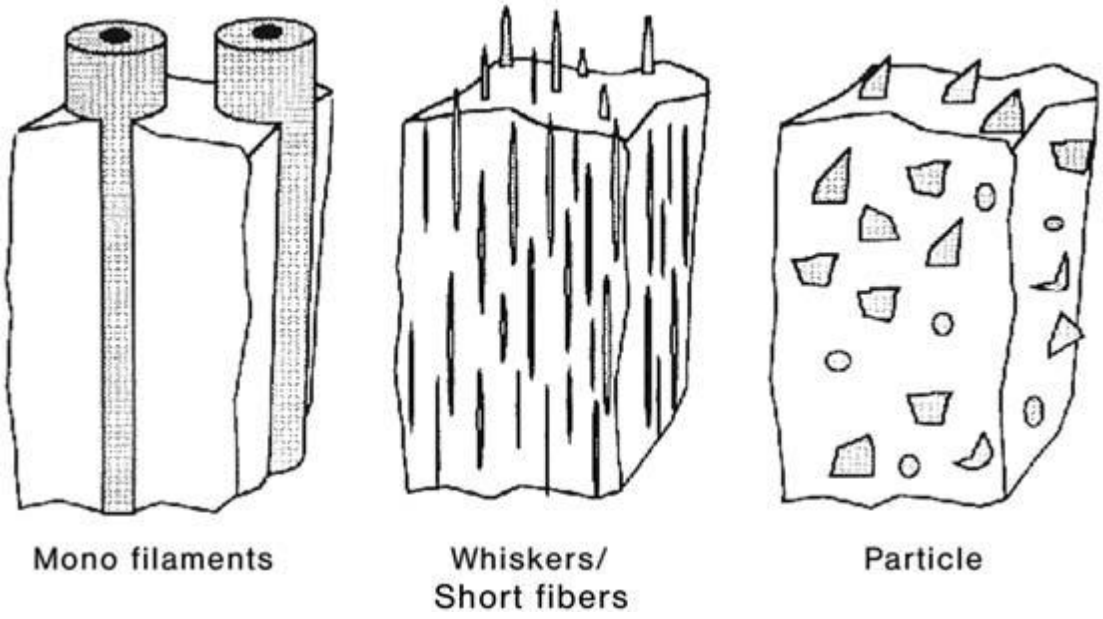


Figure 8: Schematic presentation of three shapes of metal matrix composite materials [9]

The reinforcement can serve several purposes like improve the strength to weight ratio, improve the creep and thermal shock resistance, improve the wear resistance, increase the fatigue strength, improvement in resistance to corrosive environments, etc [10]. The reinforcement materials used should be able to fulfill certain conditions [11] like having low density, good chemical and mechanical compatibility, high strength (both compressive and tensile), high temperature stability and economical cost of production and processing. These demands can be mostly satisfied by non-metallic reinforcements. Depending upon the reinforcement phases MMCs can be classified into dispersion hardened and particle composites, layer composites or laminates, fiber composites and infiltration composites. Several researches are going on in the field of MMCs because metals certainly have some distinct advantages over polymers and ceramics.

There are different routes by which a metal-matrix composite can be manufactured:

1) Solid-phase fabrication methods [12]

- Diffusion-bonding method
- Powder Metallurgy Technique

2) Liquid-phase fabrication methods

- Liquid-metal infiltration
- Squeeze casting
- Spray co-deposition
- Compocasting

3) Vapor state method

- Physical vapor deposition (PVD)

2.4.1 MMC BY POWDER METALLURGY ROUTE

This is one of the most common routes to synthesize a metal-matrix composite. The reinforcements used in this process are generally particulates or whiskers [12]. In this process, prepared powders of both matrix and reinforcement phases are mixed and blended together. This mixture is put in a mould of required shape and appropriate pressure is applied to compact the powder. This is cold pressing. Then the compacted form of the powder is heated at a sufficiently high temperature in an inert atmosphere to develop proper bonding between the matrix and reinforcement through solid state diffusion. This is the sintering process. Hot pressing can also be used to directly press the blended mixture of powders.

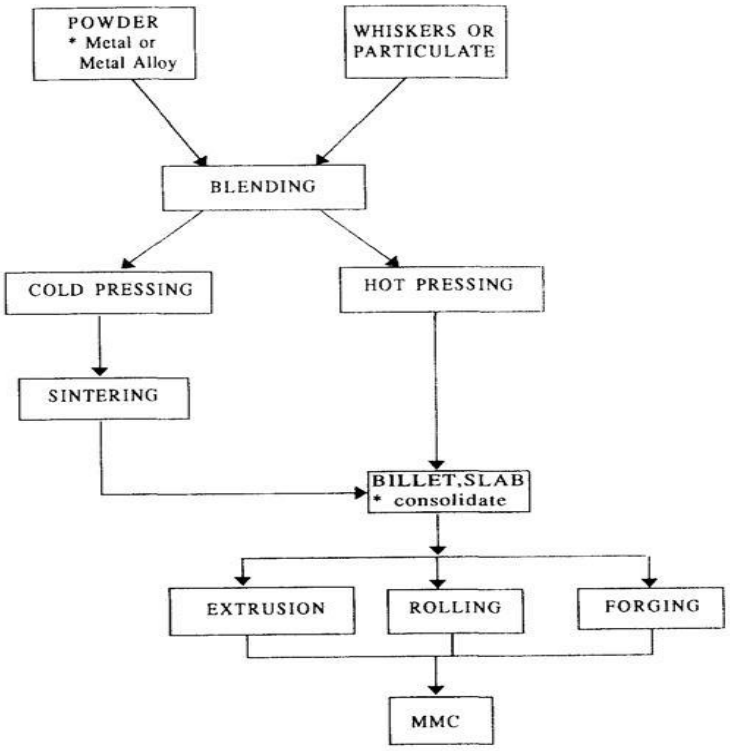


Figure 9: Flow chart of Powder Metallurgy route [12]

This process has various advantages over diffusion bonding's fusion metallurgy [13] from which some are mentioned below:-

- Lower temperature can be used as compared to fusion metallurgy of diffusion bonding.
- Forming the composite through Powder Metallurgy blending technique is easier than the casting technique.
- Particulate reinforcement is less costlier than the filaments which are continuous and have the same composition.

Some drawbacks associated with the Powder Metallurgy technique are that it is an expensive and time consuming process and it is hard to achieve uniform distribution of the reinforcement phase throughout the composite. It can be a relatively dangerous process also.

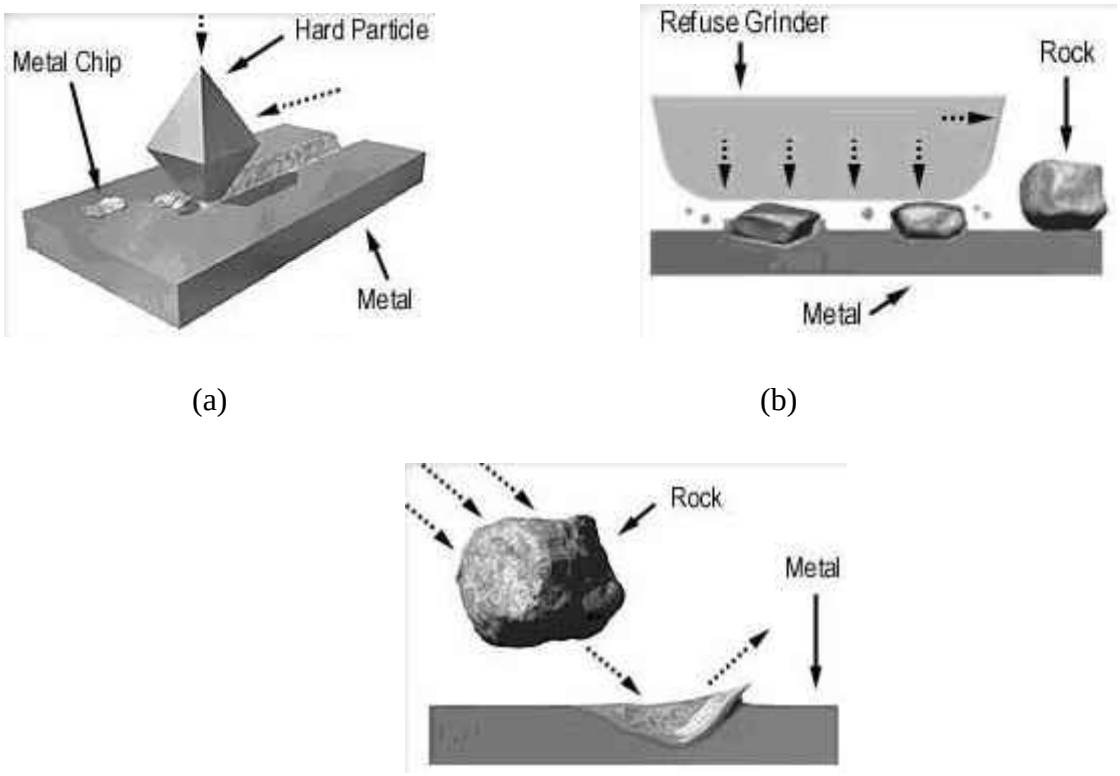
2.5 WEAR PROPERTY

Wear is the progressive loss of material from the operating surface of a solid occurring as a result of relative motion between two surfaces [14]. Wear appears as if it occurs due to relative motion between two bodies which are solid. There can be different modes or forms of wear such as abrasion, adhesion (scuffing, wiping, welding, galling and scoring), erosion and fatigue. When two surfaces which appear smooth macroscopically are brought together then contact occurs at isolated asperities on the surfaces. According to profilometry studies most of the solid surfaces inherently have roughness with varying degrees [15]. For the cases of abrasive and adhesive wear, it is assumed by the models that wear volume (wear rate) is proportional to the number of asperities in contact and related to load applied the and yield strength of the asperities [14]. As the yield strength becomes higher, the lesser will be the number of asperities that will be required for supporting of the applied load. As a result lower amount of the material is lost as the number of asperities in contact is less. It is often found that wear volume or wear rate is inversely proportional to hardness of the materials which are in contact given that hardness is proportional to the yield strength of the same materials.

2.5.1 WEAR TYPES

2.5.1.1 ABRASIVE WEAR

In abrasive wear there is ploughing of localized surface contacts by a softer mated material [16]. Abrasive wear can be caused by both metallic and non-metallic particles but mostly non-metallic particles cause abrasion. If the particle is harder than the material then serious scratching or abrasion can occur. Abrasive Wear can be further subdivided into three types namely high stress, low stress and gouging. High stress abrasion is caused due to high stress which results in more work hardening. Few examples are abrasion caused due to by rolling-contact bearings, gears, pivots and cams. In low stress abrasion there is light rubbing activity of the abrasive particles with the metal surface which causes scratches and there is no work hardening. Gouging abrasion also results due to high stress that forms grooves or gouges on the affected surface. Some examples where this can occur are impact hammers in pulverizers, parts of crusher liners, etc. Factors that can affect the resistance from abrasion are hardness, microstructure and for steel carbon content is also a factor.



(a) (b)

(c)

Figure 10: (a) Low stress abrasive wear, (b) high stress abrasive wear, (c) gouging

2.5.1.2 FRETTING WEAR

In this process wear occurs by small amplitude vibrations at mechanical connections for example at riveted joints [16]. Two oscillating surfaces of metal when brought close to one another generate tiny metallic fragments that cause abrasion. Thus the progression of wear can be attributed to both abrasive wear and mild adhesive wear. There are different factors which can affect fretting wear such as environmental conditions, contact conditions and material properties. The different parameters that can influence fretting are load frequency, number of cycles of fretting, relative humidity and temperature, etc.

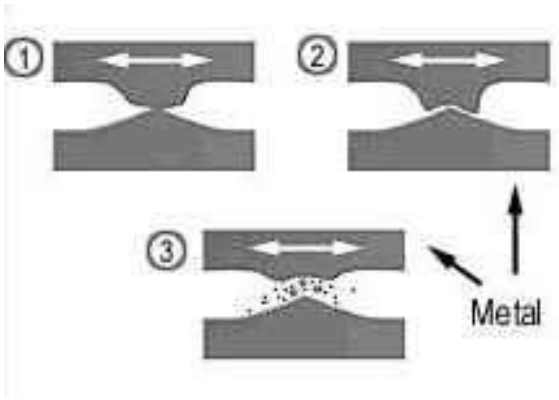


Figure 11: Schematic representation of fretting wear

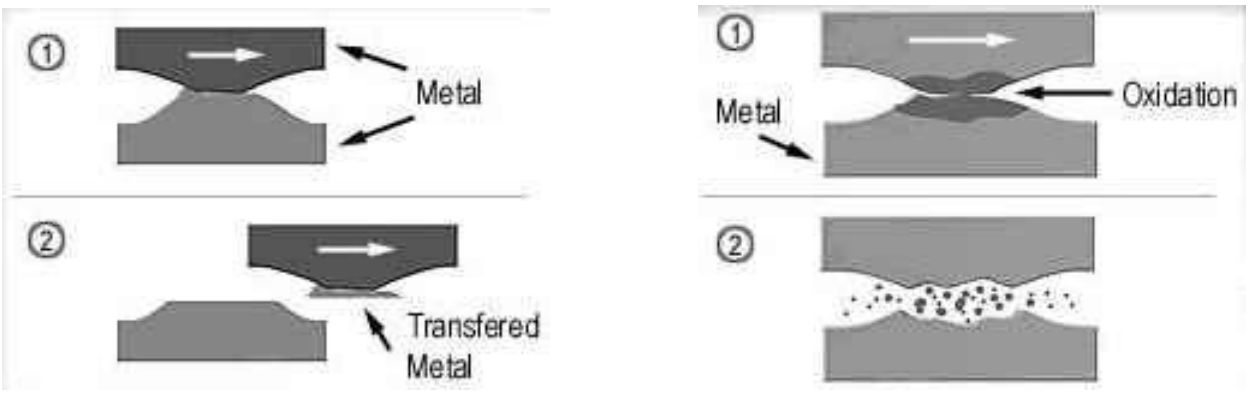
2.5.1.3 CORROSIVE WEAR

Wear occurs in this method by the influence of corrosive reagent [16]. Here electrochemical removal of material occurs along with the removal of material through physical interaction of the two surfaces in contact. These two phenomenons accelerate the overall removal of material. Wear progresses by removal of the oxide film which exposes the surface of the metal to environment, dissolution of the metal surface which is exposed, interaction between asperities in contact with the environment and interaction between the environment and plastically deformed regions. The materials which generally resist the formation of oxides can be used in corrosive wear environments.

2.5.1.4 ADHESIVE WEAR

This type of wear is caused between two metallic components which are sliding against each other under an applied load and in an environment where no abrasives are present. The name "adhesive" is given due to the forming of a strong metallic bond between the asperities in the surface of the contacting materials [16]. Mild wear or oxidative wear occurs in the case of stainless steel because the thin oxide layer on the surface prevents the formation of metallic bond between the asperities. Wear rates are high for high load application on the surface. This kind of wear is generally seen in sliding components in a valve, conveyor belts, fasteners, etc. In case of martensitic steels very good wear resistance is obtained for a minimum hardness of 53 HRC. In austenitic stainless steels, the alloy additions increase the stability of oxide film and also work

hardened hardness. These factors enable the requirement of high load for severe corrosion to occur [16].



(a) (b)

Figure 12: Schematic representation of (a) adhesive wear, (b) oxidative wear

2.5.1.5 FATIGUE WEAR

This type of wear can occur in surface of materials which are cyclically stressed. Therefore ball bearings, gears, etc normally experience the fatigue wear. The extent of fatigue wear is determined by the factors like residual stress, surface finish, microstructure and hardness. Resistance to fatigue wear can be improved by surface treatments like carburizing, nitriding and shot peening because they increase surface hardness and improve residual stress distribution [16].

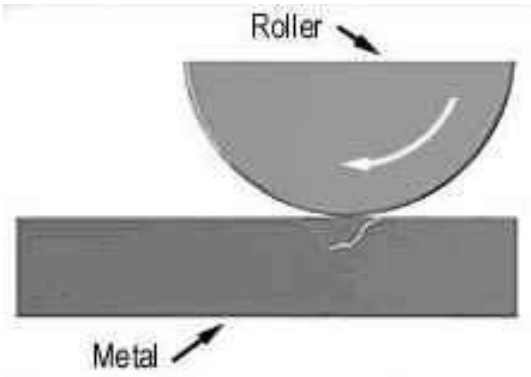


Figure 13: Schematic representation of contact fatigue

2.6 RECENT UNDERSTANDING

According Sahin *et. al.* [17] when continuous boron fibre was incorporated into the aluminium alloy (2014) matrix, its wear resistance improved by a great extent in comparison to that of the unreinforced aluminium alloy under all conditions and this was dependent not only on the fiber content but also on the orientation of fibers and other factors like applied load and rubbing speed.

From the resarch work of Candel *et. al.* [18] it can be observed that when Ti6Al4V hot rolled alloy substrate was coated with Ti6Al4V atomized powders and TiC_p to produce a metal matrix composite coating on Ti6Al4V substrate by laser cladding process, the microhardness increased along with the decrease in wear rate on increasing the volume fraction of TiC.

Wang *et. al.* [19] studied the dry sliding and lubricant sliding wear behaviours of hybrid metal matrix composites with cast aluminium alloy, A356 Al-Si as the matrix and the reinforcing materials were alumina fibers and silicon carbide particles. It can be inferred from their work that incase of dry sliding and lubricant sliding wears, the wear resistance was influenced by the orientation of fibers and addition of SiC particles.

As per the work of CURLE *et. al.* [20], with the increase in volume fraction of SiC particles in Al alloy 359 and plates of SiC particles as reinforcement produced by rheo-processing and high pressure die casting the wear rates were found to decrease on SiC abrasive mediums for F(as-cast) and T6(6 hours solution treatment at 540^0 C followed by quenching in room temperature water and then artificial aging for 10 hours at 170^0 C) conditions. However on diamond abrasive mediums the wear rates were found to increase with increase in volume fraction of SiC particles in same F and T6 conditions.

3. EXPERIMENTAL PROCEDURE

As received powders of copper and silicon carbide were mixed to form four different mixtures having a total mass of 25g each such that the volume fractions of silicon carbide in the mixtures were 0% (pure copper), 5%, 10% and 15 % respectively. From each mixture, three equal weights of small amount of mixtures were measured and taken. This made a total of 12 smaller mixtures from the four larger mixtures having 0%, 5%, 10% and 15% SiC respectively. Now all the 12 samples were taken and blended together properly mechanical attrition. This was done to achieve uniform distribution of the SiC particles throughout the copper matrix. The blended samples were then compacted using a die of diameter 12mm and applying a pressure of 2KN. Cold compaction machine was used to compact these powders.

Figure 14: Cold compaction arrangement

Now the compacted pellets were taken and heated in a furnace in an inert atmosphere at three different temperatures of 700^{o} C, 775^{o} C and 850^{o} C i.e. pellets with each composition were

sintered at these three different temperatures to further improve the strength of the compacted powder samples. Tubular furnace was used for sintering of the pellets.

Figure 15: Tubular Furnace used for sintering

The heating rate used was 5^{o}C/min and the holding time for each sample was 1 hour after the heating period. The inert gas used for sintering was argon and its purity level was 99.999%. The densities of the sintered samples were calculated and noted. The samples after sintering process were taken for XRD analysis. The model of the XRD machine used was PW-3040. The 2θ angle was varied from 20^{o} to 100^{o} and the scanning rate used was 3^{o} per minute. The XRD data for all the samples was obtained in the form of graphs.

Figure 16: PW-3040 XRD instrument

Then the samples were taken for SEM analysis. The instrument model used for the SEM analysis was **JEOL JSM-6480LV**.

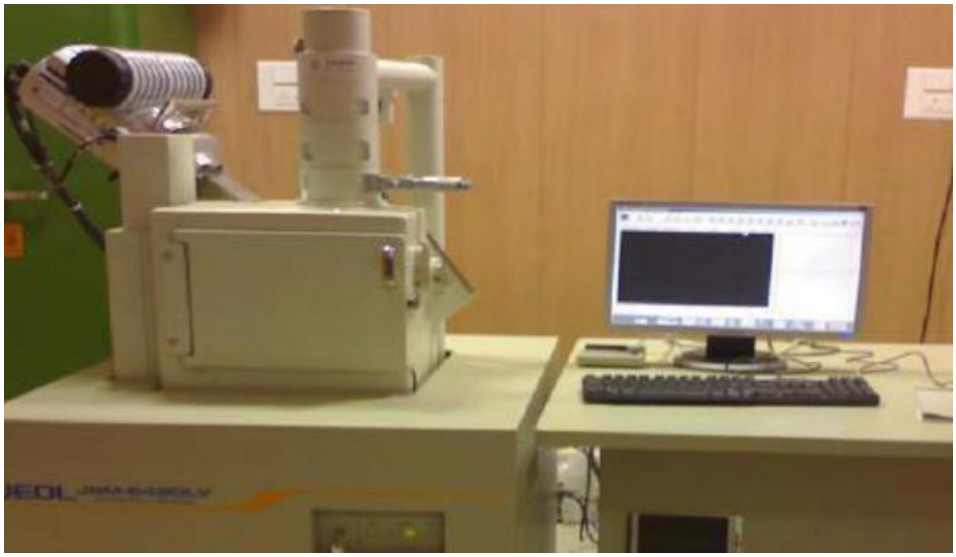


Figure 17: JEOL JSM-6480LV scanning electron microscope

A potential of 15KV was used for the scanning electron microscope and the magnification used for the samples were 17000. The size of the indication marker in the SEM graphs was 1 micron. Then EDS analysis was done on a specified region of the SEM images that were obtained for different samples to know the composition of that region and find out whether the silicon carbide particles have properly dispersed in the copper matrices or not. The SEM data and EDS analysis data were taken and analysed. Then all the 12 samples were taken for hardness measurement. Vickers hardness of all the samples was found out. The model of the instrument used for finding out the Vickers hardness was LECO-LV700. Hardness of all the samples were measured under a load of 3kg and noted down. The Vickers hardness of the samples was compared by plotting a graph between the hardness values and the composition of SiC taken at a particular temperature.

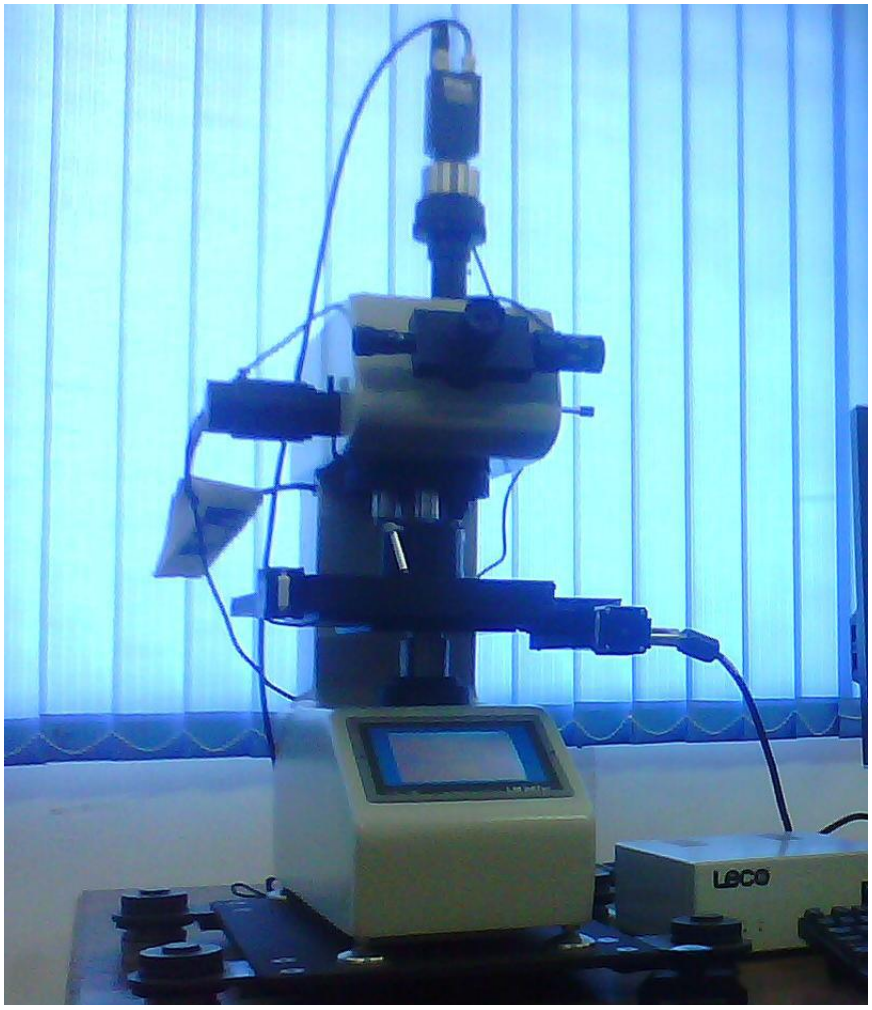


Figure 18: Vickers Hardness Testing Machine

Finally wear testing of all the samples was carried out. Wear testing in terms of sliding wear resistance of all the samples was evaluated using a ball on disc type wear testing instrument (DUCOM TR-208-M1) having a hardened steel bal indenter. Tests were carried out with an applied load of 0.5kg, 2mm diameter ball, 10 rpm rotating speed and 5 min time for the wear test. The results for the wear depth were obtained and the sliding distances were calculated by using the values of the wear depth and the process parameters. Graphs were plotted between the wear depth and sliding distance at a particular temperature for different compositions of SiC. These graphs were analyzed. The wear surfaces were once again taken for SEM analysis. The SEM images obtained for the wear surfaces of different samples were analyzed.

Figure 19: Wear testing machine

4. RESULT AND DISCUSSION

4.1 DENSITY MEASUREMENT

The theoretical and sintered densities of the samples corresponding to different compositions of SiC are given in the table below.

Sintering temperature (C)	Silicon carbide Composition	Theoretical Density (g/cc) (X)	Sintered Density (g/cc) (Y)	% Theoretical Density (%) (X/Y)
700	0 %	8.94	6.30	70.42
	5 %	8.67	6.18	71.25
	10 %	8.38	5.87	70.01
	15 %	8.10	5.67	69.90
775	0 %	8.94	6.31	70.54
	5 %	8.67	6.19	71.44
	10 %	8.38	5.95	70.96
	15 %	8.10	5.76	71.13
850	0 %	8.94	7.25	81.14
	5 %	8.67	6.94	80.02
	10 %	8.38	6.10	72.74
	15 %	8.10	5.90	72.86

The graph plotted between % theoretical density and composition of SiC is shown in the figure below.

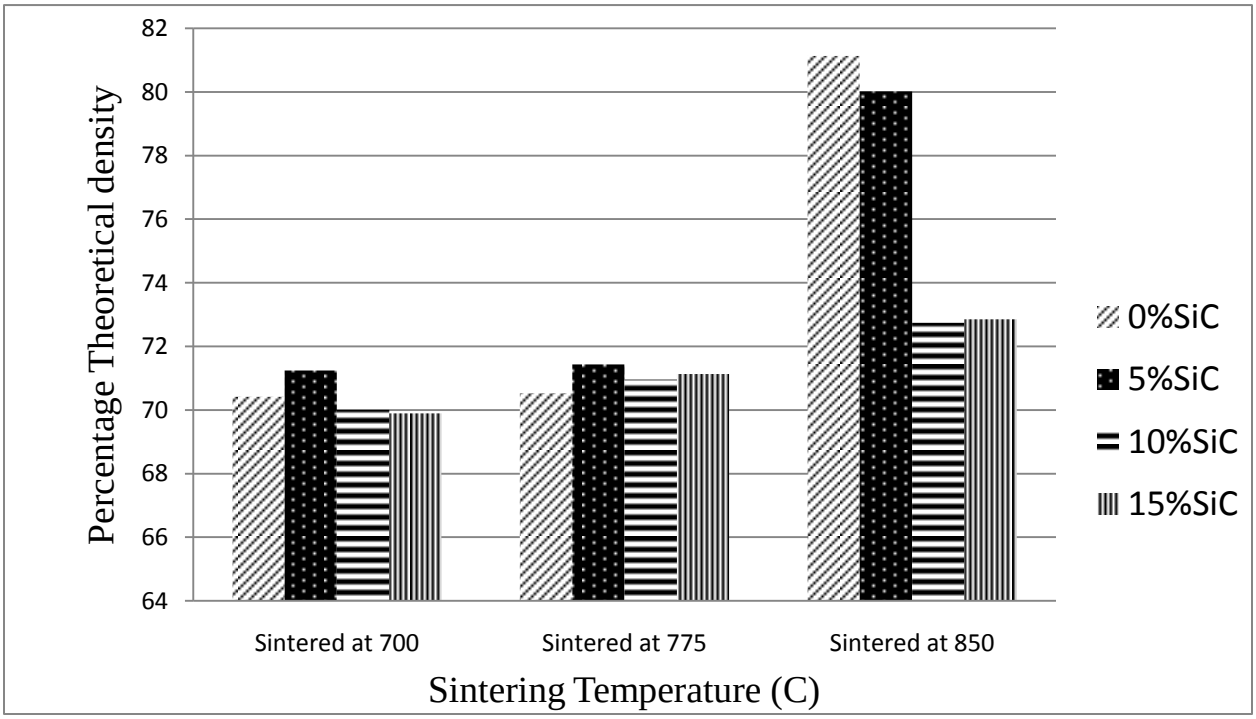
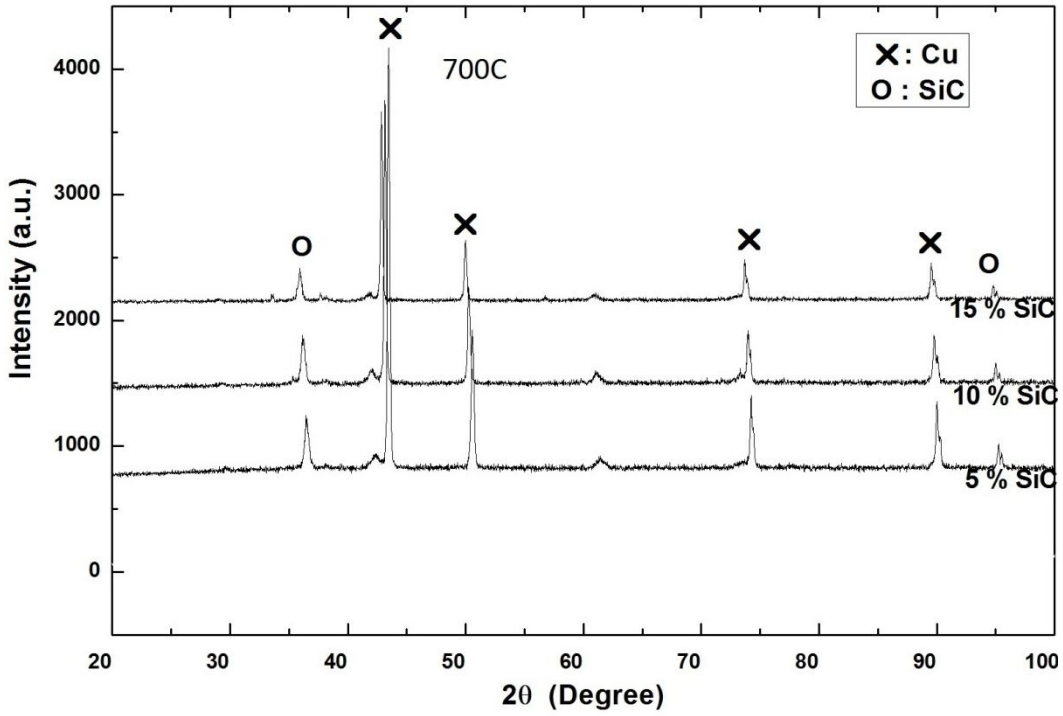


Figure 20: Variation of % theoretical density with % SiC at sintering temperatures of 700^0 C, 775^0 C and 850^0 C

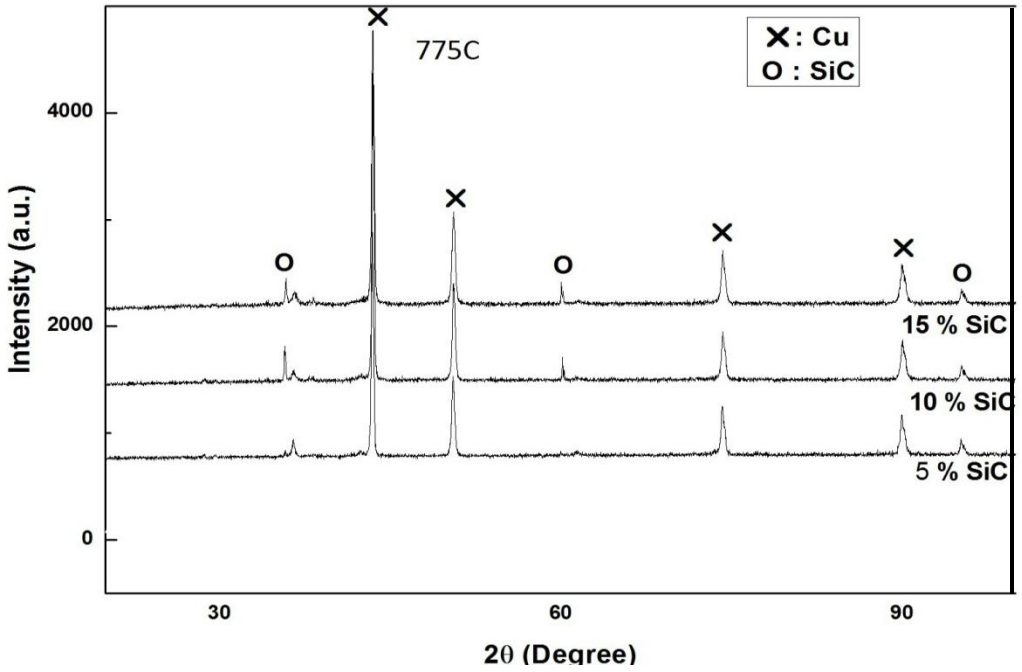
Ideally, with increase in the percentage of SiC for a particular sintering temperature there should be a decrease in % theoretical density of the composite because the theoretical density of SiC is quite lesser than that of copper. The general trend in the graph above shows that there is a decrease in % theoretical density with increase in percentage of SiC at a particular sintering temperature except for some cases where there is a slight increase in % theoretical density with increase in SiC composition for example there is a slight increase in % theoretical densities from 0% SiC to 5% SiC composition at sintering temperature of 700^o C. This may be due to the presence of some impurities like oxygen, nitrogen, etc. Also another notable fact is that the % theoretical density increases as the sintering temperature increases for the same composition of SiC. This is quite obvious because as the sintering temperature increases the bonding between the particles increase and the voids reduce in number.

4.2 XRD ANALYSIS

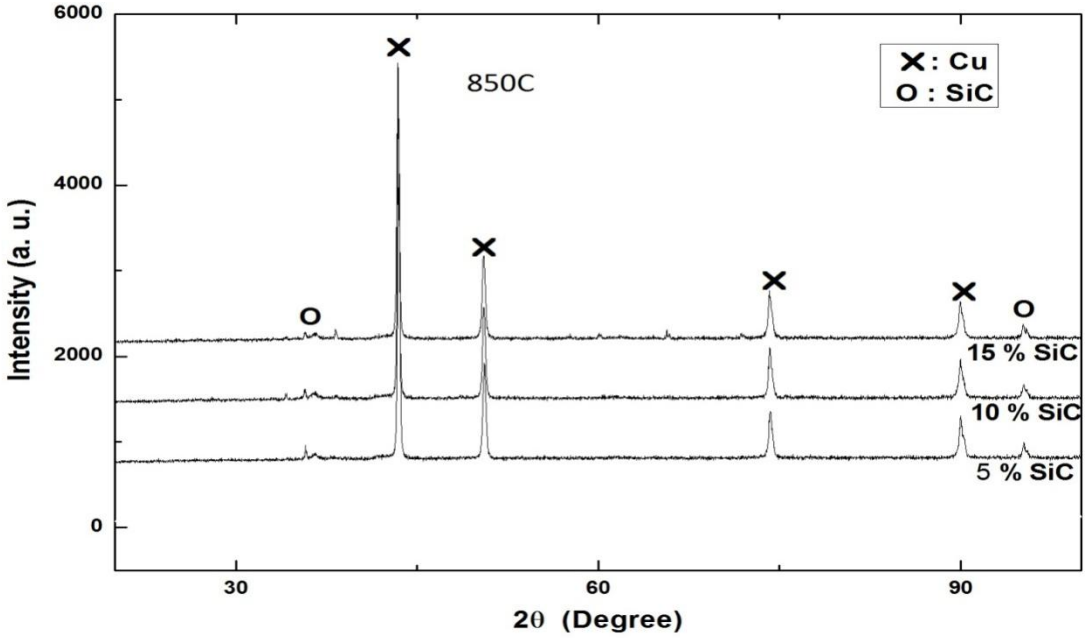
XRD plots between intensity and 2θ diffraction angle for sintering temperatures of 700^0 C, 775^0C and 850^0 C are shown in the graphs below. Each graph shows the variation of intensity with 2θ diffraction angle for three different compositions of SiC (5%, 10% and 15%) sintered at a particular temperature.



a)



b)



c)

Figure 21: XRD plots of 5%, 10% and 15% SiC compositions for sintering temperatures of a) 700^0 C, b) 775^0 C, and c) 850^0 C

The graphs clearly show the peak points corresponding to Cu and SiC respectively. It can be observed that as the composition of SiC increases for each sintering temperature, the intensity of the SiC peak also increases.

4.3 SCANNING ELECTRON MICROSCOPY

The SEM image for the sample having 10% SiC composition and sintered at 700^0 C is shown below.

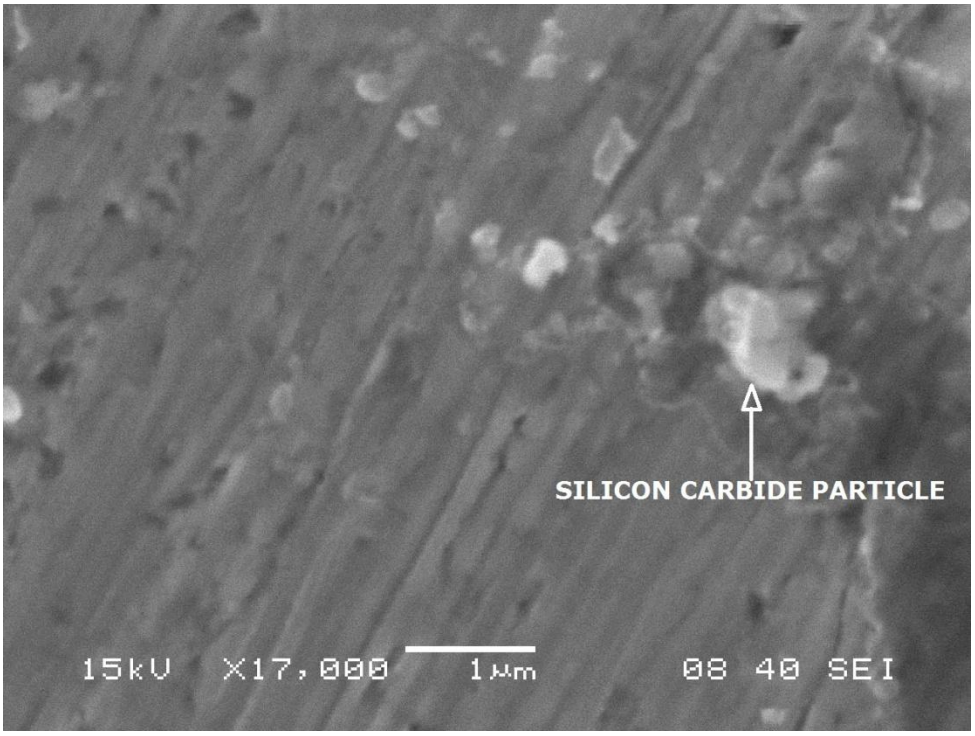


Figure 22: SEM image for sample having 10% SiC composition and sintered at 700^0 C

The SiC particle is indicated in the above image by the arrow mark. Over all spectra of EDS analysis for the same sample is given below.

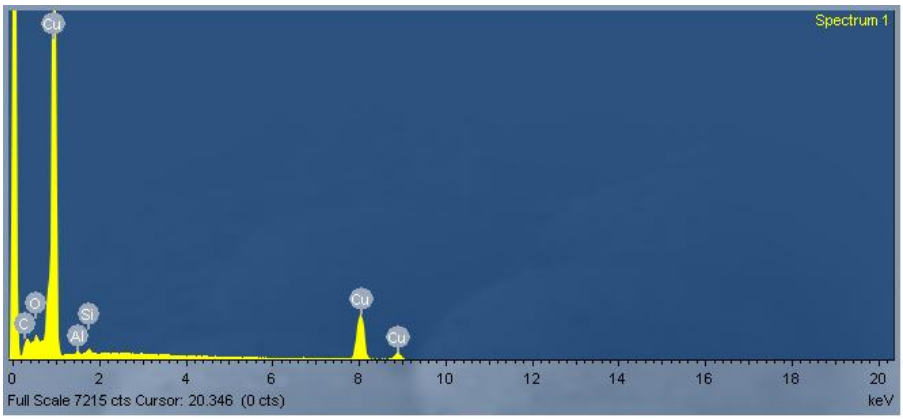


Figure 23: EDX pattern of the above SEM image

It indicates presence of Si along with Cu and some impurities like oxygen and aluminium.

4.4 HARDNESS MEASUREMENT

Sintering temperature (C)	Silicon carbide Composition	Vickers Hardness (HV)
700	0 %	34
	5 %	40
	10 %	41
	15 %	47
775	0 %	35
	5 %	40.3
	10 %	43.8
	15 %	40
850	0 %	36
	5 %	40
	10 %	44
	15 %	40

The Vickers Hardness Number (VHN) for different samples corresponding to sintering temperatures of 700^0 C, 775^0 C and 850^0 C and compositions of SiC as 0%, 5%, 10% and 15% is given in the above table. The graph plotted between Vickers Hardness Number and varying sintering temperatures at a particular SiC composition is given below:

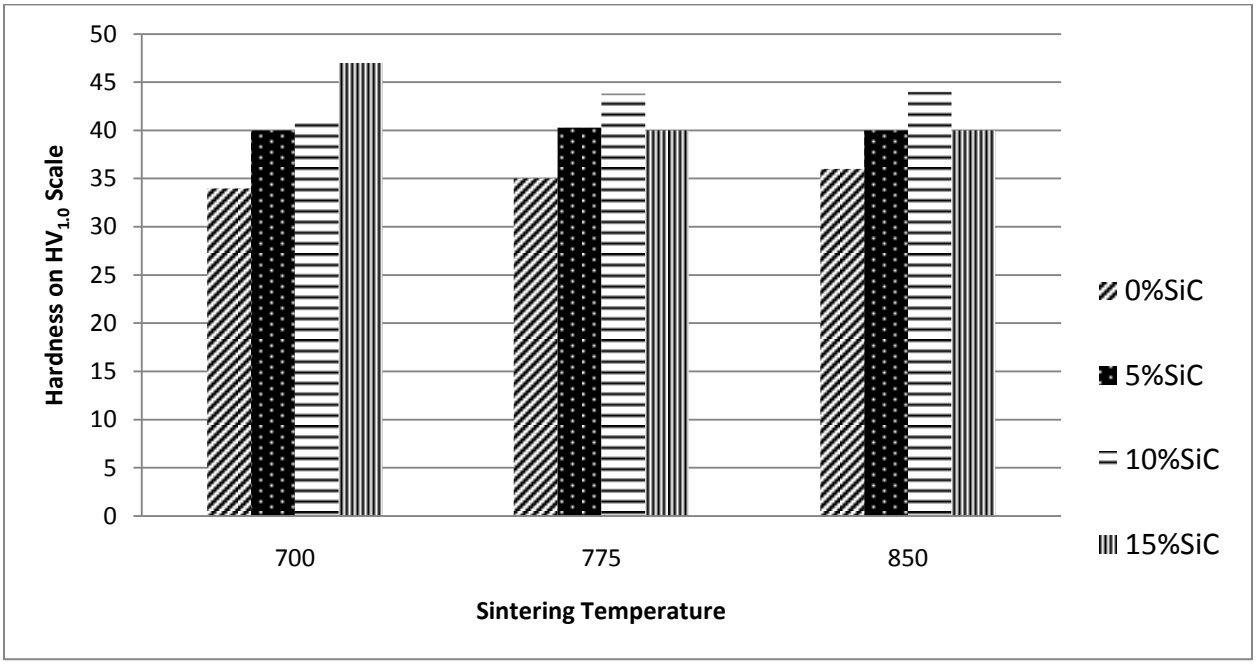


Figure 24: Variation in Vickers Hardness with % SiC composition at sintering temperatures of 700^0 C, 775^0 C and 850^0 C

Normally the hardness increases with the increase in SiC content at a particular sintering temperature because as the SiC content increases it distributes throughout the copper matrix in more uniform way and there is better transfer of load from matrix to reinforcement. Hardness also increases with the increase in sintering temperature for a particular composition of SiC. This happens because as the sintering temperature increases the voids get reduced in number due to better bonding between the particles.

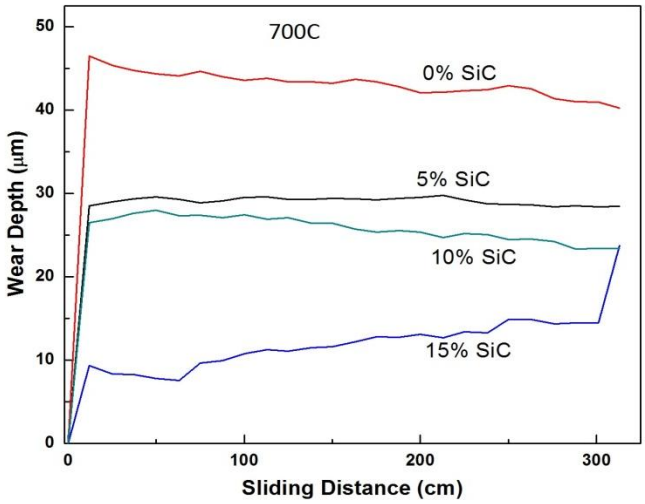
In the above graph it can be observed that as the sintering temperature increases the hardness of a particular composition of SiC increases except for some cases where the hardness slightly decreases or almost remains same. When we observe the case of 15% SiC there is a decrease of hardness from 700^0 C to 775^0 C and the hardness value at 850^0 C is same as that obtained at 775^0 C. The main reason for this deviation can be that SiC did not uniformly distribute throughout the

matrix of copper due to inadequate mixing. Also presence of impurities in the composite can certainly reduce its hardness and increase the brittleness.

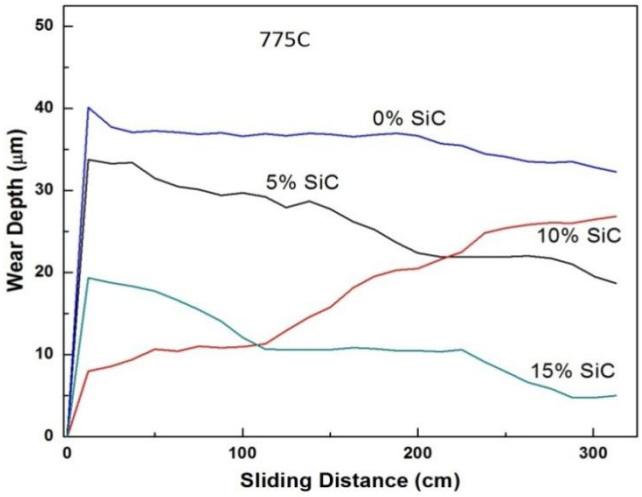
Another observable fact from the above graph is that at a particular sintering temperature the hardness increases for an increase in SiC percentage. However, hardness slightly decreases from 10% SiC to 15% SiC at sintering temperatures of 775^0 C and 850^0 C. This may be due to the presence of impurities like oxygen, nitrogen, etc or due to non-uniform distribution of SiC in the copper matrix.

4.5 WEAR BEHAVIOR

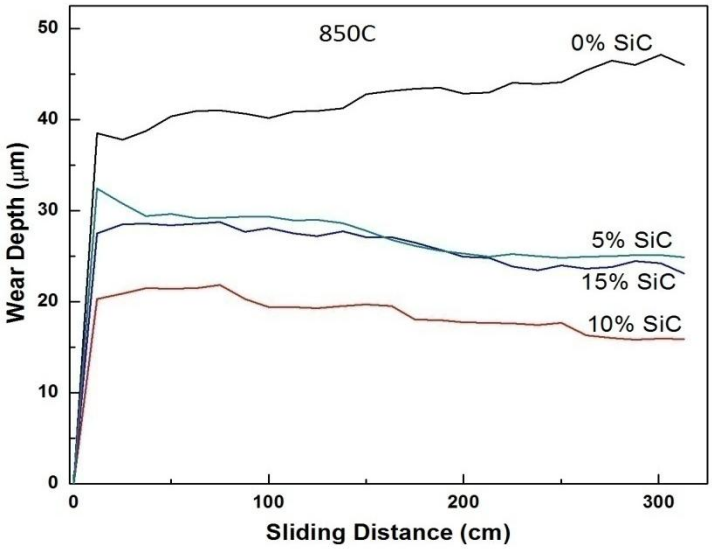
The data collected from wear test of all the samples were converted to graphs between the wear depth and the sliding distance. The plots related to wear are shown below:



a)



b)



c)

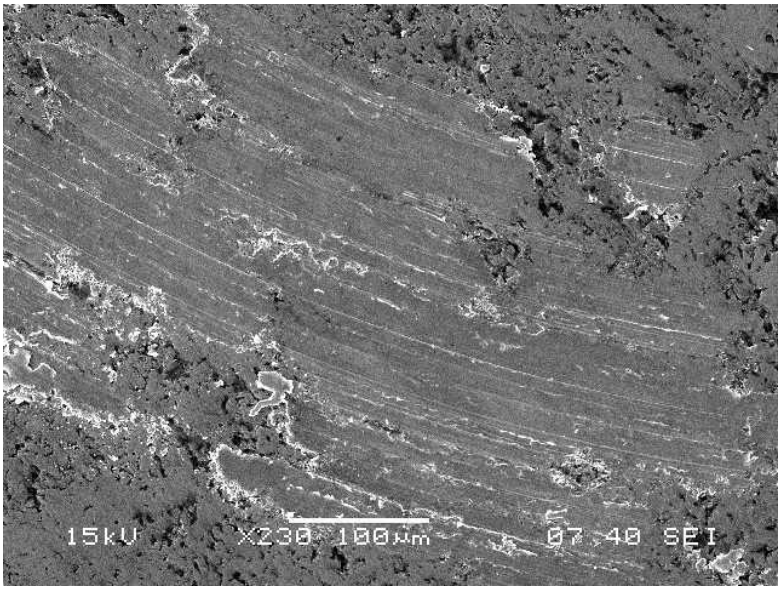
Figure 25: Variation of wear depth with sliding distance for SiC compositions of 0%, 5%, 10%, 15% at particular sintering temperatures of a) 700^0C, b) 775^0 C and c) 850^0 C

The above graphs show the variation of wear depth with relation to the sliding distance for different compositions of SiC at a particular sintering temperature. It can be clearly seen that as the SiC composition increases for any sintering temperature the wear depth decreases i.e. more wear has occurred for the sample having minimum SiC for a particular sintering temperature. This indicates that wear resistance of the composite increases with increase in the percentage of silicon carbide. For all the cases maximum wear depth is found for the samples containing 0% SiC. Only in the case of 15% SiC sintered at 850^0 C it is found that more wear has occurred as compared to 10% SiC sample. This is quite in sync with the hardness results we got. According to the hardness results, the hardness decreases from 10% SiC to 15% SiC sintered at 850^0 C. It has been often found that hardness is inversely proportional to the wear rate. So, as the hardness reduces from 10% SiC to 15% SiC at the sintering temperature of 850^0 C, the wear has increased. Also initially the wear depth for 15% SiC sample sintered at 775^0 C is found to be more than that of 10% SiC. This also may be due to the fact that 10% SiC sample sintered at 775^0 C had more hardness than the 15% SiC sample at same sintering temperature. As the sliding distance increases for the same sample it can be seen that the wear depth goes on increasing. This can also

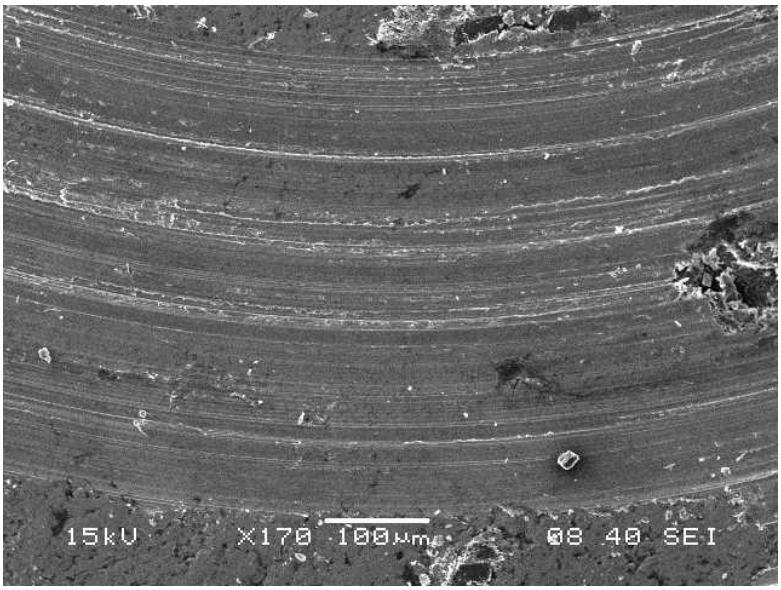
be seen for 15% SiC sample sintered at 700^0 C. This indicates that the wear resistance of these samples reduces with increase in time or sliding distance. Non-uniform distribution of SiC could be a reason for this. Momentary downward slope of some wear plots may be due to adhesive wear of the soft Cu substrate. Soft Cu may have got welded with the hardened steel ball resulting in decrease in wear depth. So, mainly the wear is of adhesive mechanism and partially of abrasive one, mainly when SiC % increases.

4.5.1 SEM ANALYSIS OF WEARED SURFACE

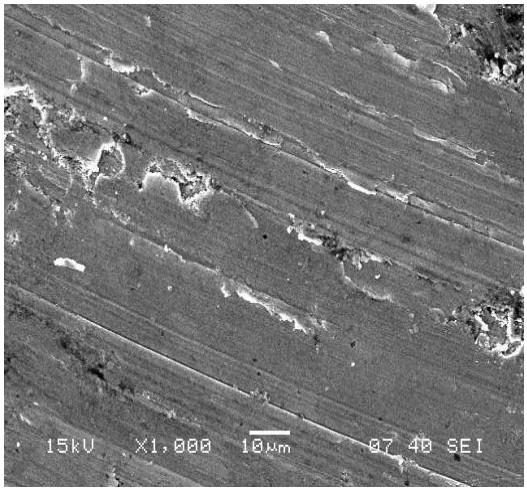
The SEM images of the wear surfaces of pure copper sample and 5% SiC sample sintered at 700^0 C are shown below at different magnifications:

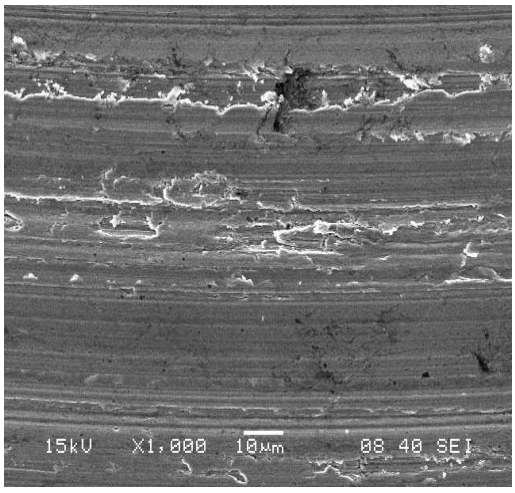


a) Pure Copper (sintered at 700^0 C) at magnification 230



b) Cu-5%SiC (sintered at 700^0 C) at 170 X





c) Pure Cu (700^0C) at 1000 X

d) 5% SiC (700^0 C) at 1000 X

Figure 26: SEM images of wear surface at sintering temperature of 700^0C for a) Pure Cu at 230 X, b) 5% SiC at 170 X, c) Pure Cu at 1000 X and d) 5% SiC at 1000 X

From the wear images above it can be seen that there is more rubbing activity in case of Cu-5% SiC composite sintered at 700^0 C which indicates the presence of SiC particles on the wear surface which are responsible for abrasive wear.

At 1000 magnification it can be observed that more wear has occurred in the case of pure copper (700^0 C) than Cu-5%SiC (700^0 C) mostly due to the fact that hardness of 5% SiC sample sintered at 700^0 C is more than that of pure copper sample sintered at 700^0 C.

5. CONCLUSION

The following conclusions were drawn from the present study:

1) a) The percentage theoretical density decreased with the increase in SiC content of the different samples sintered at a particular temperature leaving a few cases where the % theoritical density slightly increased most probably due to the presence of impurities.

b) The percentage theoretical density increased with the increase in sintering temperature for a particular composition of the composite due to better bonding between the particles and reduction in the number of voids at higher temperature.

2) The intensity for the SiC peaks obtained from the XRD test increased with the increase in the percentage of SiC at a particular sintering temperature.

3) a) The Vicker's Hardness Number (VHN) increases with the increase in SiC composition at a particular sintering temperature. Few deviations occurred like slight decrease in hardness with increase in SiC percentage at the same sintering temperature mainly due to the presence of unwanted impurities like oxygen, nitrogen, etc.

b) The Vicker's Hardness Number also increased with the increase in sintering temperature for a particular composition of SiC with slight exceptions possibly due to impurities present or due to non-uniform distribution of SiC throughout the copper matrix.

4) a) The wear depth decreases with increase in the percentage of SiC in the copper matrix i.e. wear resistance of the composite increases with increase in SiC content.

b) The wear rate is found to be inversely proportional to the hardness values. Generally, with the increase in SiC content at a particular sintering temperature, hardness increased and the wear rate on the other hand decreased. Even for the exceptions where hardness slightly decreased with increase in % SiC at a particular sintering temperature the wear was found to be more.

c) With the increasing in sliding distance the wear depth generally increased with momentary downward slope due to adhesive wear of the soft copper phase causing welding of the copper substrate with the hardened steel ball resulting in decrease of the wear depth.

d) With the increase in SiC composition at a particular sintering temperature, there was increase in the amount of abrasive wear on the surface due to more rubbing activity by the SiC particles.

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